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PRELIMINARY RESULTS OF THE SCHATZ FUEL CELL RESEARCH PROJECT

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Abstract

We report preliminary results of the Schatz Fuel Cell Research Project. The goal of this two year project is the design, construction, and testing of a 1.5 kW proton exchange membrane fuel cell (PEMFC). The final fuel cell stack will run on H₂/Air at very low pressure as a component in the Schatz Solar Hydrogen Project. We report the characteristics of the cell test station and test results for 50 and 150 cm² cells in 1, 2, and 4 cell stacks. This research is being carried out in collaboration with the Center for Electrochemical Systems and Hydrogen Research at Texas A&M University.

1. INTRODUCTION

Background and Project Objectives

The Schatz Fuel Cell Research Project is an outgrowth of the Schatz Solar Hydrogen Project [1]. Initiated in the fall of 1989, the Schatz Solar Hydrogen Project is a stand-alone photovoltaic energy system at the Humboldt State University (HSU) Telonicher Marine Laboratory that uses hydrogen as the energy storage medium and a PEM fuel cell as the regeneration technology. Its goal is to demonstrate that solar hydrogen can provide a non-polluting, reliable, renewable, and abundant energy source for our society now and in the future.

Difficulties in obtaining a reliable, appropriately sized, and reasonably priced PEM fuel cell for incorporation into the hydrogen project provided the initial motivation for the Schatz Fuel Cell Research Project. Beginning with construction of the laboratory and test station in June 1992, this two-year project has progressed rapidly and follow-up PEM fuel cell development projects are anticipated. This research has been undertaken in collaboration with the Center for Electrochemical Systems and Hydrogen Research (CESHR) at Texas A&M University.

The overall goal of this project is the design, fabrication, and testing of a 1.5 kW very low pressure H₂/air PEM fuel cell as stationary power supply for Schatz Solar Hydrogen Project. Specific objectives of this project are:

- to design and outfit a laboratory suitable for PEM fuel cell research, testing, and fabrication which includes a machine shop so that all parts can be produced in-house;
- to develop expertise in the design, production, and testing of electrode-membrane assemblies for PEM fuel cells;
- to develop control software and hardware that would permit safe and reliable unattended operation of the PEM fuel cell while minimizing associated parasitic loads;
- to develop a simulation model for use in cell and stack design;
- to design, fabricate, and test a series of 50 cm² cells in 1, 2, and 4 cell stacks capable of providing efficient operation on H₂ and air at very low pressures, low temperatures, and utilizing internal reactant humidification;
- to design, fabricate, and test a series of 150 cm² cells in stacks of increasing cell number that are capable of providing efficient operation on H₂ and air at very low pressures, low temperatures, and utilizing internal reactant humidification; and
- to produce, test, and install a 1.5 kW H₂/Air PEM fuel cell as the back-up power source at the Schatz Solar Hydrogen Project.

Paper Contents

Substantial progress has been made to date. In this paper, we describe the fuel cell laboratory and test station, preliminary results of modeling cell response, and the testing and performance characteristics of 50 cm² and 150 cm² cells in 1, 2, and 4 cell stacks.

2. LABORATORY AND TEST STATION CAPABILITIES

Fabrication and Machining Capability

The process of technology development involves an iterative process of design, fabrication, testing, and evaluation. To improve efficiency and maintain direct control of each step, the Schatz Energy Research Center (SERC) includes an in-house machine shop equipped with a computer controlled (CNC) milling machine, manual milling machine, lathe, drill press, grinder, and band saw. These tools allow us to produce parts of almost any required shape and number in metal, plastics, graphite, or other materials. This capability makes it possible for a design to proceed from concept through testing and evaluation without ever leaving the lab. Parts may also be quickly modified or remade as the need arises during testing. Further, since the person doing the fabricating is also involved in both design and testing, errors of communication are rare and feedback is assured. The result is a tight, closed development loop which allows work to proceed in an efficient and timely manner.

At present, the only major fuel cell components not produced at SERC are the proton exchange membranes, the electrodes, and the membrane/electrode assemblies. The membrane/electrode assemblies are obtained from the Center for Electrochemical Studies and Hydrogen Research at Texas A&M University under a collaborative agreement and are fabricated using commercially available membranes and electrodes. However, we expect to soon bring this function in-house as well and in time to develop our own electrodes.

Fuel Cell Test Station

Our fuel cell test station is a custom built system designed to test fuel cells up to 1.5 kW. Its key features include (a) autonomous operation, (b) complete control of operating conditions, and (c) automated testing ability. A schematic of the test station is shown in Fig. 1.

Autonomous operation means the test station can safely conduct tests unattended. A computer monitors fuel cell operation (voltage, current, temperature) and lab safety sensors (smoke alarm, combustible gas alarm) to shutdown the station when any of these inputs are out of allowable bounds.

Cell temperature, current, gas flow rate, and other aspects of fuel cell operation are carefully controlled. Temperature of the water circulating through the stack is controlled thermostatically. A custom built electronic load provides control of the fuel cell current up to 150A. Combining this with a mass flow controller on the air supply allows us to precisely set the stoichiometry. Hydrogen flow is measured but not controlled and a solenoid valve allows the hydrogen to be purged from the cell periodically.

The automated testing features of our system include the ability to perform measurements of the relationship between cell potential and current density (i.e., E_i -curves) and operate at programmed sequences of flows and currents. During E_i -curve measurement, the air flow rate is held constant while current is stepped logarithmically at lower current densities (where Tafel relationships dominate) and then linearly at the higher current densities (where ohmic and mass transport resistance become important). Step size and duration are selectable with the only restriction being a maximum rate of 60 samples per second. E_i -curve results are immediately available for analysis at other lab workstations via a local area network.

Control Software

Fig. 2 shows the monitoring panel of the test station control program. The inlet and outlet conditions are shown on the left for air and on the right for hydrogen. All readings are measured values except for the outlet flows and inlet oxygen flow. The outlet flows are computed as the difference between the inlet flow and the gas consumption computed from cell current while the inlet oxygen flow is computed as 21% of the air flow. In the center box are the operating

conditions of the fuel cell. The measured values here are the current, each of the cell voltages, and the fuel cell temperature. The gas consumption rates are calculated from the current and number of cells. The stoichiometry is simply oxygen consumed divided by oxygen in. Stack voltage is computed as the sum of the individual cell voltages.

3. Ei-CURVE MODELS

Development of Model

In order to characterize the performance of individual membrane/electrode assemblies operating under different conditions and to facilitate the design of fuel cell stacks, we have extended commonly used models to incorporate description of mass transport limitation effects. The relationship between cell potential and current density under conditions that are not mass transport limited is commonly described by a Tafel relationship with an added resistance term [1, 3]:

$$E = E_o - b \cdot \log(i) - R \cdot i \quad (1)$$

where:

- E = cell potential (mv)
- E_o = open circuit potential (mv)
- = E_r + b · log(i_o)
- E_r = reversible cell potential (mv)
- i_o = exchange current density (ma/cm²)
- R = resistance (ohm·cm²)
- i = current density (ma/cm²)
- b = Tafel slope (mv/decade)

For low current densities (e.g., less than 400 ma/cm²), nonlinear parameter estimation software can be used to estimate the parameters in equation (1) (i.e., E_o, b, and R). These estimates generally provide a very precise characterization of the E vs. i curve yielding correlation coefficients in excess of 0.99 as shown in Fig. 3. At higher current densities, the observed potential decreases much more rapidly than equation (1) would predict as also shown in the same figure. The difference (ΔE) between the observed cell potential and the cell potential predicted using the equation (1) fitted to the low current density data provides an estimate of the potential loss due to mass transport limitation. It can be shown that ΔE may be approximated as an exponential function of the current density:

$$\Delta E = a \exp(k \cdot i) \quad (2)$$

where:

$$\begin{aligned} a &= \text{proportionality coefficient (mv)} \\ k &= \text{exponential coefficient (cm}^2/\text{ma)} \end{aligned}$$

Other simple functions such as a single term power function or a diode equation-like function also provide a good approximation to the relationship between ΔE and i . Combining equations (1) and (2) gives:

$$E = E_0 - b \cdot \log(i) - R \cdot i - a \exp(k \cdot i) \quad (3)$$

which describes the complete E vs. i curve. Fig. 3 shows a comparison of the data and the curve fitted over the complete range of current density using equation (3). Estimates for E_0 , b , and R obtained by fitting equation (1) using data where $i \leq 400$ ma/cm² and by fitting equation (3) using all data are statistically indistinguishable.

We utilize equation (3) to characterize E vs. i relationships in the remaining sections of this paper. The agreement to equation (3) is generally very good with correlation coefficients in excess of 0.99. Kim et al. [3] have also found that equation (3) provides a precise and useful description of Ei relationships over a wide range of temperature, pressure, and reactant conditions.

4. CELL AND STACK DEVELOPMENT

Our goal in the design of the fuel cell system (i.e., the stack and associated auxillary systems) is to maximize the net system efficiency. Since Swan et al. [4] and Amphlett et al. [5] have both demonstrated that compressor power requirements constitute a major parasitic load that is not offset by improved efficiency, we have designed our system to operate at very low reactant pressure, i.e., < 2 psig. Our approach to the design, fabrication, and testing of this system has been to progressively increase the active area from 50 to 150 cm² and number of cells from 1 to eventually a 40 cell stack of cells. By working out the fundamental cell design on a smaller scale, we have speeded development and reduced costs.

From the inception of the project in June 1992 until May 1993, all of our work involved single 50 cm² cells. Since then we have 1) fabricated and tested 2 and 4 cell stacks of 50 cm², 2) designed, fabricated, and tested an effective system to provide internal humidification, 3) designed, fabricated, and tested an effective system to control stack temperature, and 4) designed, fabricated, and tested 1, 2, and 4 cell stacks of 150 cm² with internal humidification and stack temperature control.

In scaling up from 50 to 150 cm² active area, we have observed no degradation in stack performance as evidenced by the Ei-curve in Fig. 4 and the power density curve in Fig. 5. Both figures show cell-average results for 4 cell stacks operating at < 2 psig air and H₂ pressure and a temperature of 41-42°C. The air flow rates per unit area are approximately twice as high for the 50 cm² stack vs. the 150 cm² stack (i.e., 40 vs. 22 sccm/cm²). The cell voltage and peak power density are actually higher for the 150 cm² stack for current densities < 700 ma/cm². At our projected operating current density when installed at the hydrogen project, the stack efficiency should exceed 50% (HHV).

As expected, the performance of the stacks at higher current densities is strongly dependent on air flow rate. Fig. 6 illustrates the influence of air flow rate on the Ei-curves for the 4 cell 150 cm² stack. As air flow is varied from 3.3 to 33.3 sccm/cm², the onset of mass transport limitation is progressively pushed out toward higher current densities. In vehicles and other variable load applications, control of air flow rate will be necessary to permit operating near the maximum net system efficiency over a wide range of loads.

5. CONCLUSIONS AND FUTURE OBJECTIVES

In this paper we have reported on the progress to date of the Schatz Fuel Cell Research Project. The fuel cell laboratory and test station are complete and fully functional. We have extended commonly used Ei-curve models so that we can precisely characterize the performance of individual membrane/electrode assemblies operating under different conditions and can project the performance of fuel cell stacks. We have designed, fabricated, and tested 50 cm² and 150 cm² cells in 1, 2, and 4 cell stacks and have achieved very good performance with these stacks at low temperatures and very low pressures.

By July 1994, we anticipate completing a 40 cell, 150 cm² stack for incorporation into the Schatz Solar Hydrogen Project. In addition, we have recently entered into a cooperative agreement with the Institute of Transportation Studies at University of California, Davis to design, fabricate, and test a 5 kW and a 20 kW PEM fuel cell for incorporation into a vehicle. We look forward to the challenges this new project will bring.

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